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NOISE AND THE FLUCTUATIONS AND STABILIZATION OF POWER IN A CO_2 LASER

By

Wojciech Michalski, Romuald Nowicki, Edward F. Pliński

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Noise and the fluctuations and stabilization of power in a CO_2 laser

Wojciech Michalski, Romuald Nowicki, Edward F. Pliński

Institute of Telecommunications and Acoustics,
Wroclaw Polytechnic

Many uses of gas lasers, e. g. in metrological and holographic devices, require stable output power for long periods of time. Numerous studies have been devoted to this problem, especially with repect to helium-neon lasers [1,2] and argon lasers [3].

The CO_2 laser, which generates radiation with a 10.6 μm wavelength, is one of the best known molecular gas lasers. Because of the possibility of obtaining continuous power on the order of several hundred watts, the possibility of pulsed operation, and high energy efficiency, in excess of 20%, this laser has been a subject of great interest for the past ten years in a number of laboratories, especially as a tool for working various types of materials. The most important parameter of the laser beam in this kind of application is maximum power, while stability is less important. In many

cases, however, e. g., in precision working of thin sheets of plastics or in working of thin layers of metals and semiconductors in microelectronics, a beam power from several to twenty watts is sufficient, and it is more important to provide stability, recurrence, and the precise level of power.

The most frequently used type of high-power molecular CO_2 laser is a laser with a slow-flowing mixture of gas, a tube one to several meters in length, and a relatively simple design which does not provide stable and repetitive operation.

This article gives the results of studies of laser-beam noise and studies of the main sources of output-power instability, and it also describes tests of an electronic system for stabilizing the output power of a CO_2 laser.

The experiments used a CO_2 laser with a tube whose working section was approx. 0.5 m long and which had an internal diameter of 7 mm. The laser resonator was composed of two internal mirrors: a gold-coated reflecting mirror with a radius of approx. 1.1 m, and a plane germanium transmitting mirror. The resonator was mounted in clamps on two Invar rods connected with a rigid metal frame. In order to insure the resonator against shocks and vibrations, the base was placed on a special granite anti-shock table.

The structural scheme of the laser is presented in fig. 1. A slow-flowing CO_2–N_2–He mixture with a 1 : 1 : 2 ratio was used, with a total pressure of 5 to 10 torr. The discharge in the laser tube was initiated and maintained by an unstabilized feed with a maximum of 15 kV; the discharge current was 5–15 mA. The discharge tube was connected in series with a discharge-stabilizing resistance R = 200 kΩ. Maximum radiated power was 2.5 W.

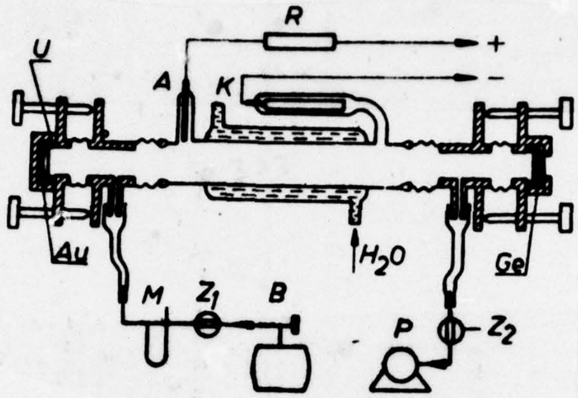

Fig. 1. Structural scheme of CO_2 flow laser: A — anode, K — cathode, Au — gold mirror, Ge — germanium mirror, U — seals, P — rotary pump, B — cylinder, M — oil pressure gauge, Z_1 and Z_2 — valves.

The research work on CO_2 laser radiation noise covered the following problems:

— measurements of total radiation noise in the 1 Hz — 150 kHz band,

— measurements of the radiation noise spectrum,

— radiation-noise and discharge-current correlation measurements.

An uncooled (Cd, Hg) Te radiation detector was used [5].

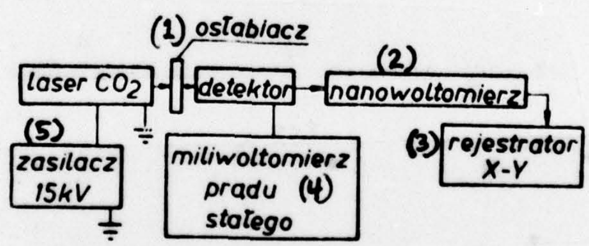

Fig. 2. Block diagram of system for measuring total radiation noise and noise spectrum

1 — attenuator, 2 — nanovoltmeter, 3 — X-Y recorder, 4 — dc millivoltmeter, 5 — 15 kV feed

The total noise and noise spectrum measurements were performed with the system diagrammed in fig. 2. In the total radiation noise

measurements a UNIPAN V-233 nanovoltmeter was used as an amplifier with a low internal noise level, high amplification, and a 1 Hz – 150 kHz transmission band. The voltage patterns from the detector, amplified by the nanovoltmeter, were registered as a function of time on an Endim 2001 X-Y recorder. Allowance was made for the internal noise of the detector when the results were compiled. The average value of radiated power was taken as a reference level. The noise profiles obtained on the recorder were averaged over a period of several minutes and reduced by the averaged value of internal noise of the detector and nanovoltmeter system. The value obtained is referred to the mean value of voltage on the detector load and expressed in dB as the coefficient F. The table gives values of coefficient F for some pressures and discharge currents. It confirms the clear dependence of the averaged value of total noise on the discharge current. A characteristic feature of this dependence is the occurrence of minimum total noise for the optimum value of the discharge current. The low level of total radiation noise is asso-

Values of coefficient F in dB

p(Tr) \ I	$I < I_{op}$	$I = I_{op}$*	$I > I_{op}$
4	−39	−58,4	−54
8	−64	−77.3	−59,7
12	—	−80	−68,3

*) I_{op} corresponds to maximum beam power

ciated with very weak spectral components for this noise. Fig. 3 gives the noise spectra in the form of a dependence: the ratio of the direct current at detector s to the actual value, averaged over several minutes, of signal N, measured at a given frequency by a V-233 selective nanovoltmeter, is a function of the frequency. The

spectrum has components with an 85–100 dB level in the 1.5–20 Hz band, a very strong 35 Hz component with a 55–70 dB level, and a 100 Hz component, which is related to the feeder hum, at the 70–80 dB level. The components with higher frequencies are below the internal noise level of the system being measured, i. e., about 110 dB.

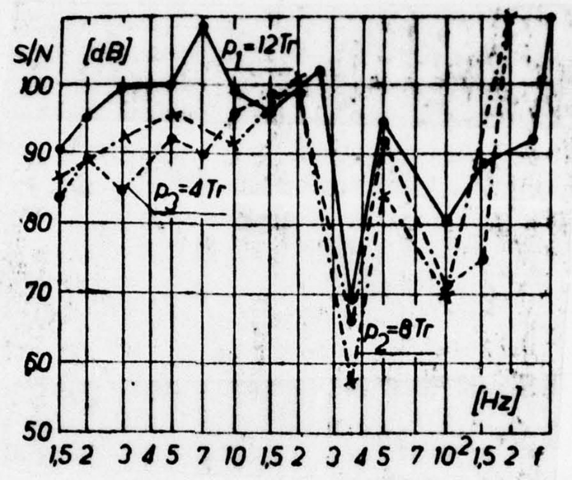

Fig. 3. Spectrum of CO_2 laser radiation noise

The low level of radiation noise has its basis in the relatively weak correlation of discharge-current noise and radiation noise revealed by measurements. This correlation was studied by measuring the effect of laser beam modulation with the help of the variable component of the discharge current. The block diagram of the system measured is given in fig. 4. In all measurements the modulation factor for the current (m_I) was maintained at a constant level of 14%. The effect of modulating a beam of radiation,characterized by the modulation factor m_p, was found to be a function of the total pressure of the mixture, the discharge current, and the modulating frequency. Fig. 5 shows the dependence of the ratio m_p/m_I as a

function of frequency for three pressures and optimum discharge-current values. It is worth noting the relatively weak correlation

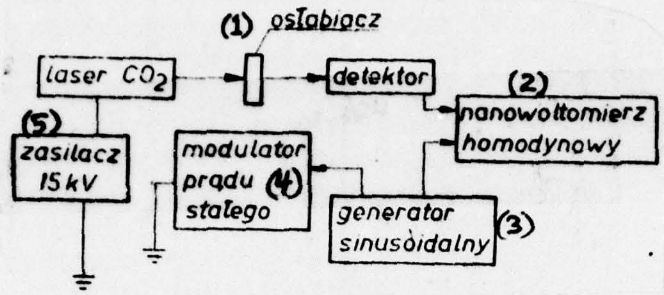

Fig. 4. Block diagram of system for measuring correlation of discharge-current noise and radiation noise

1 – attenuator; 2 – homodyne nanovoltmeter; 3 – sinusoidal generator; 4 – dc modulator; 5 – 15 kV feed

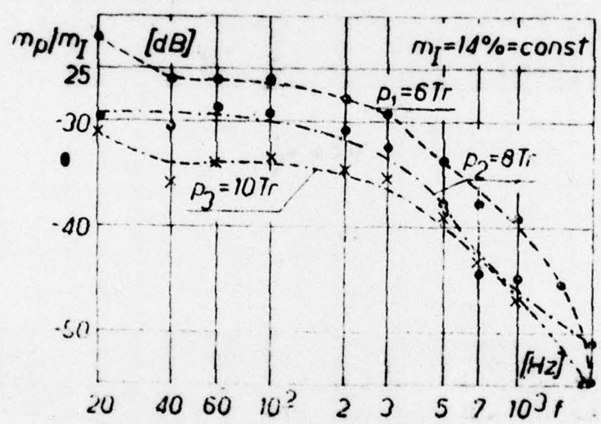

Fig. 5. Ratio of beam modulation factor m_p to discharge-current modulation factor m_I as a function of frequency

of radiation noise and discharge-current noise, as well as the very rapid decrease in the ratio m_p/m_I with the increase in modulating frequency. For the sake of comparison, the effect of modulation in He-Ne lasers under typical operating conditions is nearly an order of magnitude stronger, and it occurs in a considerably wider fre-

quency range, from several hertz to several hundred kilohertz [6].

The measurements of the stability of average laser power encountered very great difficulties. It was found that the 10.6 μm, type (Cd, Hg)Te radiation detectors available domestically displayed such great thermal drifts that measurement of the mean power value was impossible, even though the detector was placed in a passive thermostat.

From the previously mentioned results of noise spectrum measurement it appears that the spectral components of fluctuations in the frequency range above 1 Hz are very small, about 2–3 orders of magnitude less than in the He-Ne laser. Therefore, to take advantage of the fact that the power of a CO_2 laser is subject to variation in mean value which is generally slow, with rapid fluctuations being very slight, a bolometric detector was used to measure and record the mean power value. A conical absorber, wound from a single layer of copper wire, was used in a calorimeter for precise measurements of laser power [7]. This detector shows a relatively small lag (the time constant for small signal variations is about 0.3 s) and low thermal drift (about 0.08 mV/30 min with a working signal of about 10 mV. This drift is more than two orders of magnitude less than in semiconductor detectors. Detector sensitivity is approx. 0.14 V/W.

The results of average laser power measurements are presented in fig. 6. There were great variations in the mean value of CO_2 laser output power, averaging ±(15–30)%/30 min and as much as ±60%/30 min in many measurements. The main cause of output-power instability in a flow-type laser is the fluctuations or slow variations in the

mixture of gas in the tube. With pressure variations of about 7% (0.5 torr at 7.2 torr) and a fixed discharge current, variations in power of about 30% were observed; with pressure variations of 3% (0.2 torr at 7.2 torr) the power varied by 5%. With a fixed feed voltage a pressure variation in the tube causes a simultaneous change in the discharge current, which substantially increases the variations in output power. For example, a change of about 8% in the discharge current, at fixed pressure, caused power variations of about 9%. Significant changes in output power were also caused by temperature variations in the water which cooled the discharge tube. For example, a temperature change of about 3% on the Kelvin scale caused output power variations of about 4%.

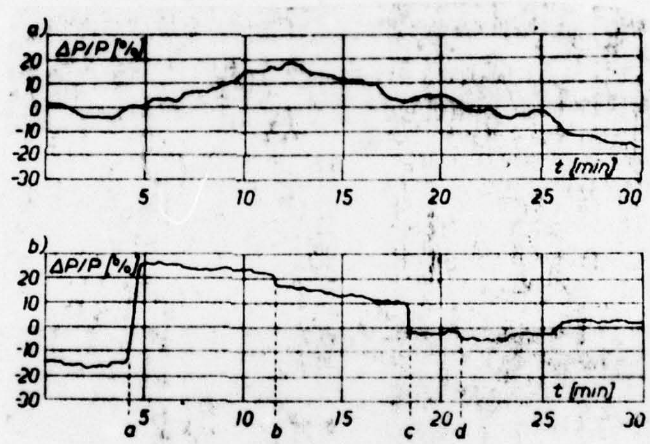

Fig. 6. Time behavior of mean value for CO_2 laser power: a) – with fixed operating conditions, b) – with variable laser operating conditions, *a* – pressure variation $\Delta p/p$ = +7%, *b* – pressure variation $\Delta p/p$ –3%, *c* – discharge current variation $\Delta I/I$ = +7.7%, *d* – coolant water temperature variation $\Delta I/I$ = +3%

In order to reduce variations in the mean value for the output power of a CO_2 laser, it is necessary to eliminate the possibility of variations in the pressure of the gas mixture, in the discharge

current, and in the temperature of the discharge tube. At the same time, the mechanical concentration of the laser must provide very good stability for the positioning of the resonator mirrors. These requirements are very difficult to meet for medium-power or high-power lasers, with structures several meters in length, and can lead to a significant increase in the cost of laser equipment.

In cases where it is permissible to reduce laser power by 20–30%, costly design elements can be avoided by using an electronic system to stabilize CO_2 laser output power [8]. An example of this type of system is presented schematically in fig. 7. The system makes use of the strong dependence of the laser output power on the intensity of the discharge current. The source of the deviation signal is the same kind of detector that has been used to measure the mean value of power. The deviation signal, after amplification, is used to con-

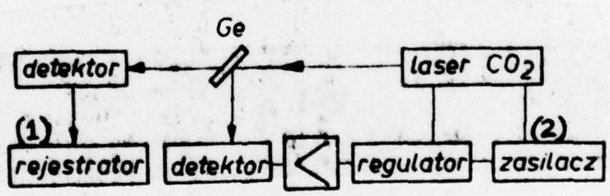

Fig. 7. Block diagram of system for stabilizing CO_2 laser output power
1 – recorder; 2 – feed

trol the discharge current so as to compensate for variations in the mean value of laser power. The laser working point must be well-chosen on the slope of the output-power characteristic as a function of discharge current. Lasers whose power is stabilized by means of the system described cannot operate with a discharge current which corresponds to the maximum output power. Total amplifi-

cation of the feedback loop was about 117 dB.

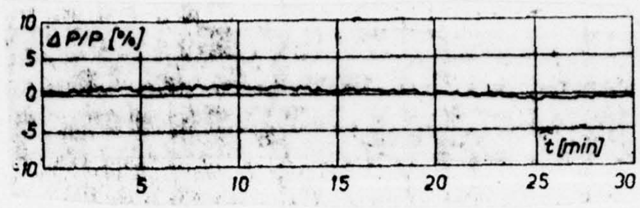

Fig. 8. Profile of mean value for power of CO_2 laser with stabilizing system

The incorporation of a stabilizing system brought about a significant reduction in variations in the mean value of laser power. Power variations were reduced by as much as ±(0.3–0.8)%/30 min and ±(0.15–0.30)%/5 min for laser power instability of ±(15–20)%/30 min. With power instability of ±60%/30 min a correction of ±2.4%/30 min was achieved. A typical profile of stabilized output power is presented in fig. 8. Slow periodic changes in power are probably caused by thermal tuning of the resonator within the whole area of generating lines. On the other hand, characteristic small jumps in power are probably related to a generating jump from one line in an area to another line with different amplification.

In sum, it may be stated that CO_2 laser radiation noise is less than that of the He-Ne laser. The CO_2 laser is better suited for telecommunications, especially since 10.6 μm radiation is less attenuated in the atmosphere than the visible light of other lasers. On the other hand, the fluctuations of output power in CO_2 lasers, especially in flow-type lasers, are greater than in other types. However, the fluctuations can be counteracted by using a power stabilizing system connected in series with the laser tube and the

high-voltage feed.

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